RELATIVISTIC GREEN'S FUNCTION MODEL AND OPTICAL POTENTIAL

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NuFact15: XVII International Workshop on Neutrino Factories and Future Neutrino Facilities, Rio de Janeiro 10-15 August 2015

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Green's Function Model

GF

F. Capuzzi, C.Giusti, F.D. Pacati, Nucl. Phys. A 524 (1991) 281

nonrelativistic GF (e,e')

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RGF

A. Meucci, F. Capuzzi, C.Giusti, P.D. Pacati, PRC 67 (2003) 054601 relativistic RGF (e,e')

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RGF

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+ PVES, ν scattering, CCQE NCQE……

In RGF FSI in the inclusive QE scattering accounted for by the complex optical potential describing elastic proton-nucleus scattering.

The formalism can translate the flux lost toward inelastic channels (imaginary part of the OP) into the strength observed in inclusive reactions.

OP powerful tool to include important contributions not included in other FSI models based on the impulse approximation.

RGF successful in the description of data…… BUT

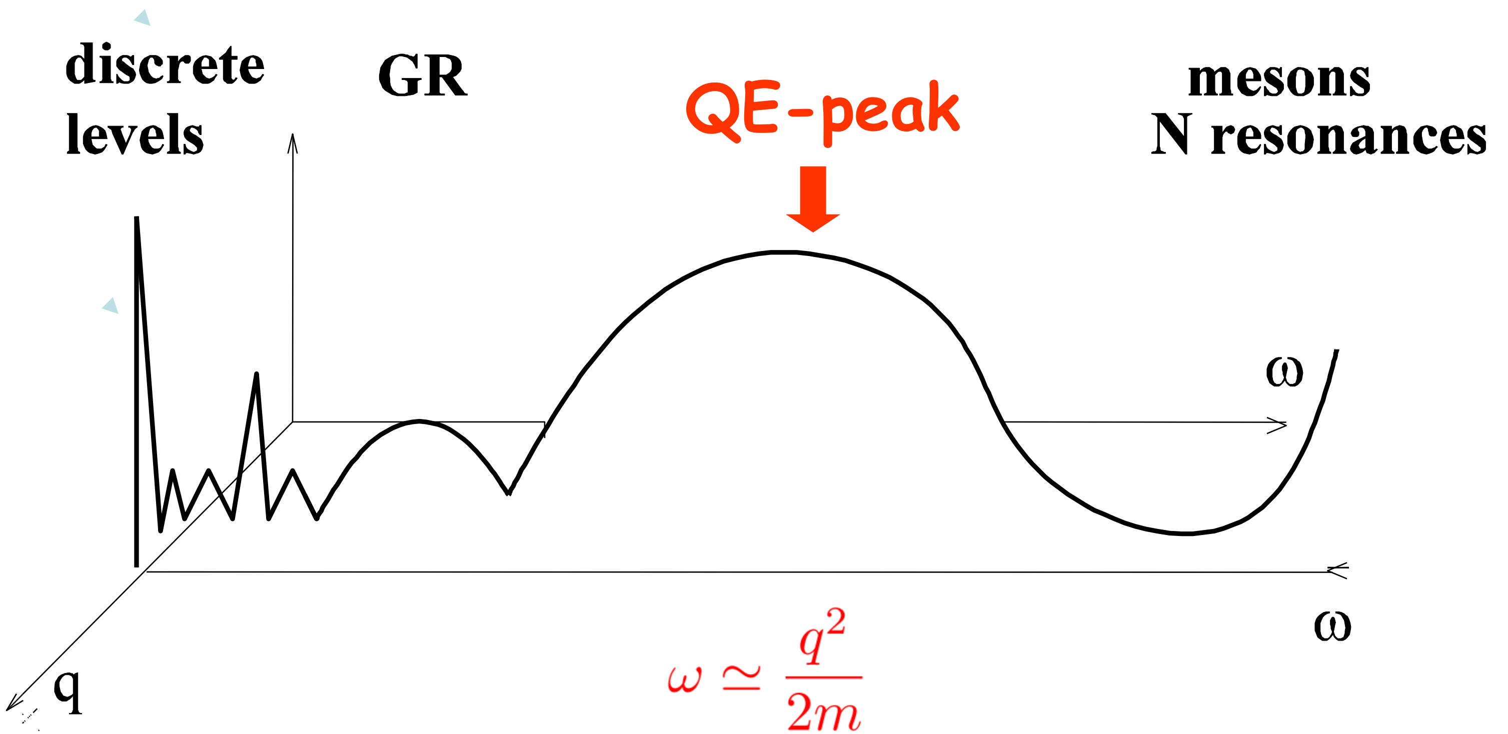
BUT there are some caveats

The use of a phenomenological OP does not allow us to disentangle and evaluate the role of a specific inelastic contribution

Available proton-nucleus scattering data do not completely constrain the shape and size of the OP

Different OP's available, with different imaginary parts, give different inelastic contributions in RGF calculations and produce theoretical uncertainties on the predictions of the RGF model

nuclear response to the electroweak probe



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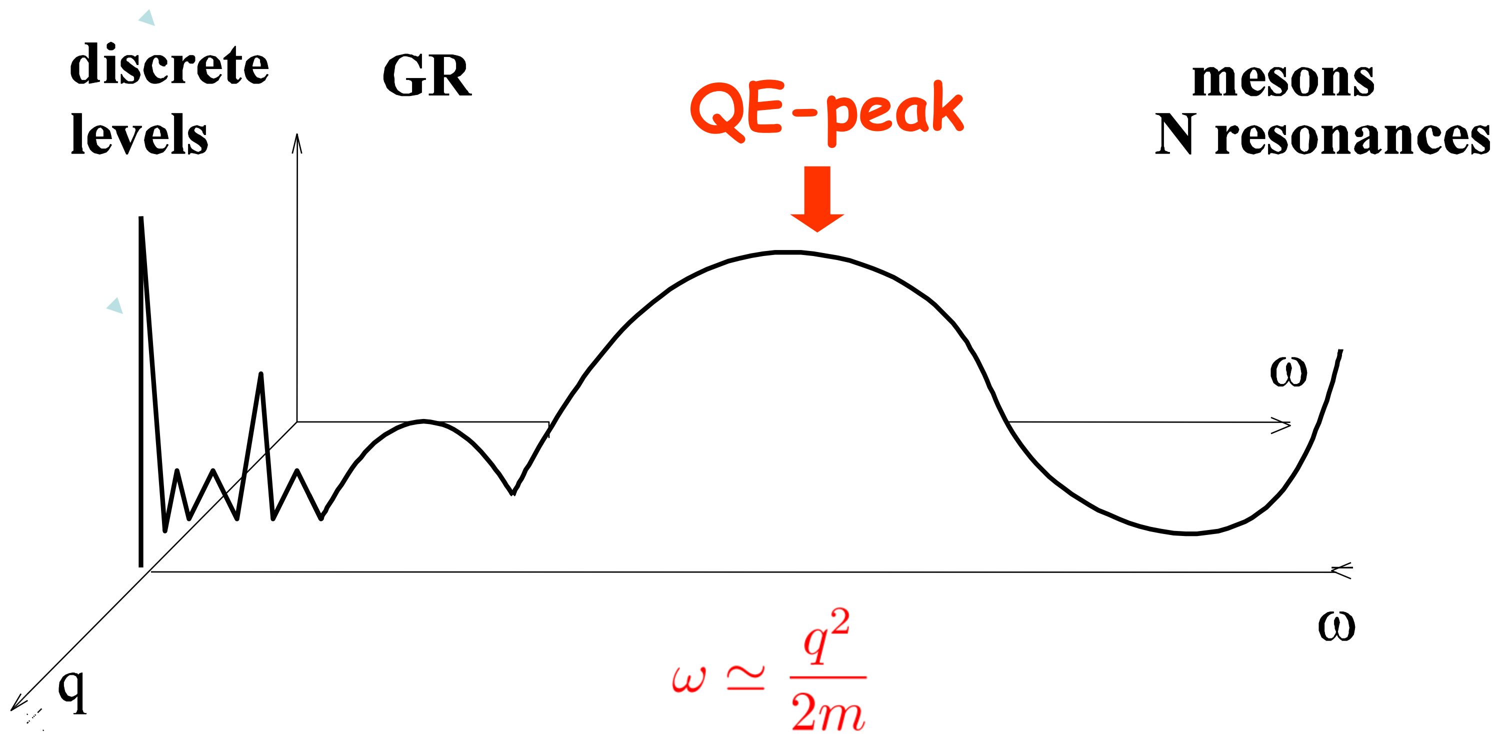
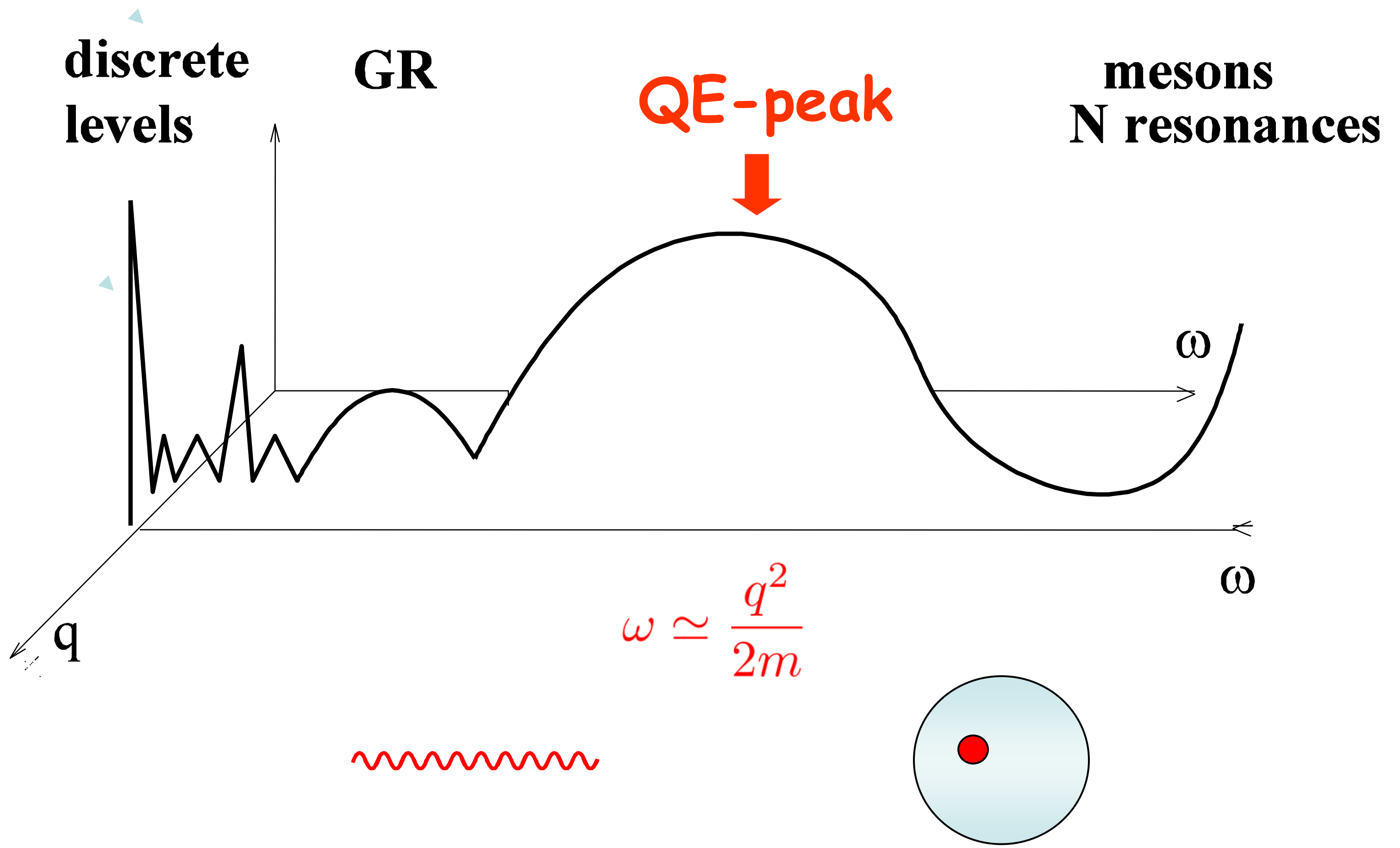


QE-peak dominated by one-nucleon knockout

nuclear response to the electroweak probe



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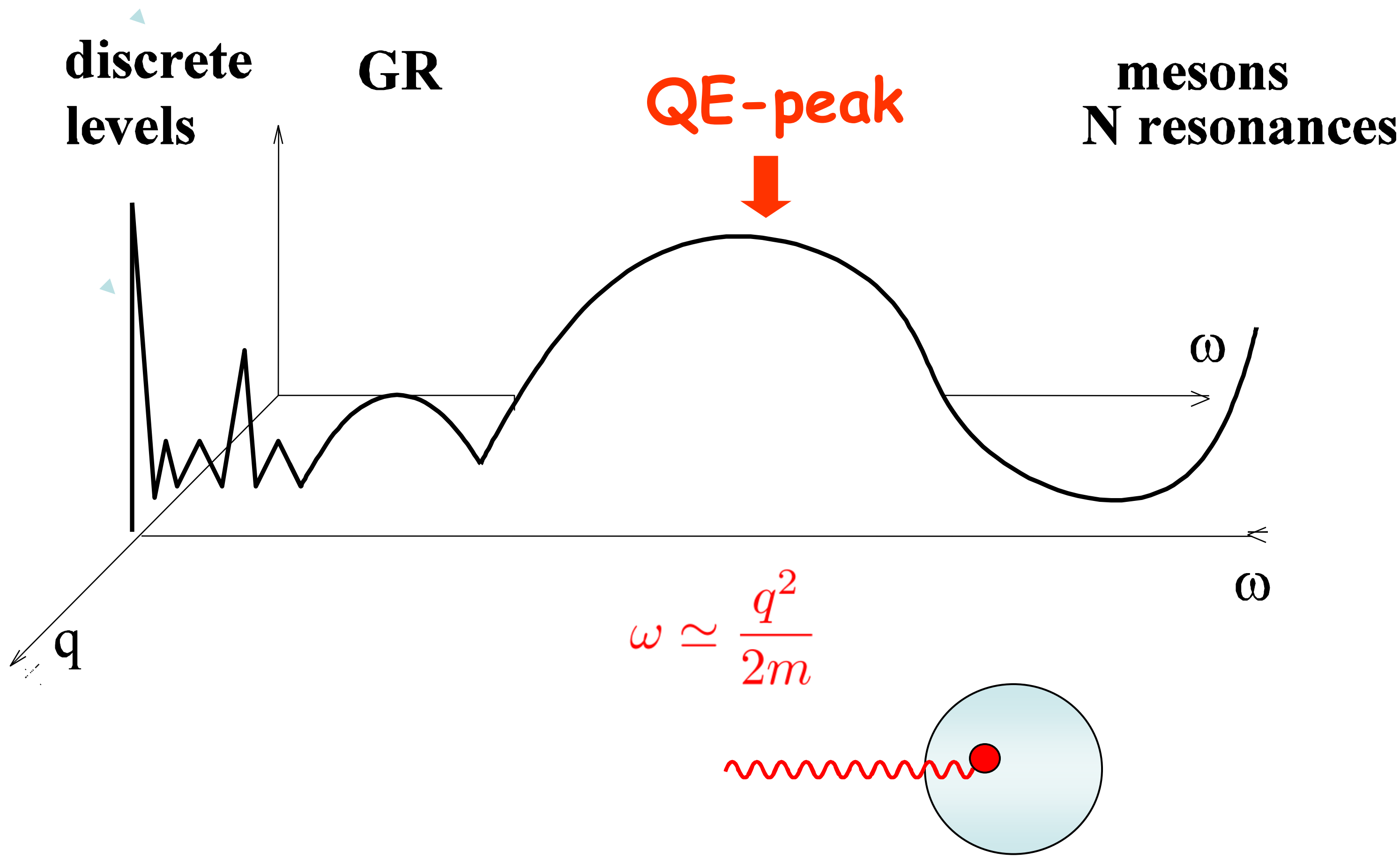

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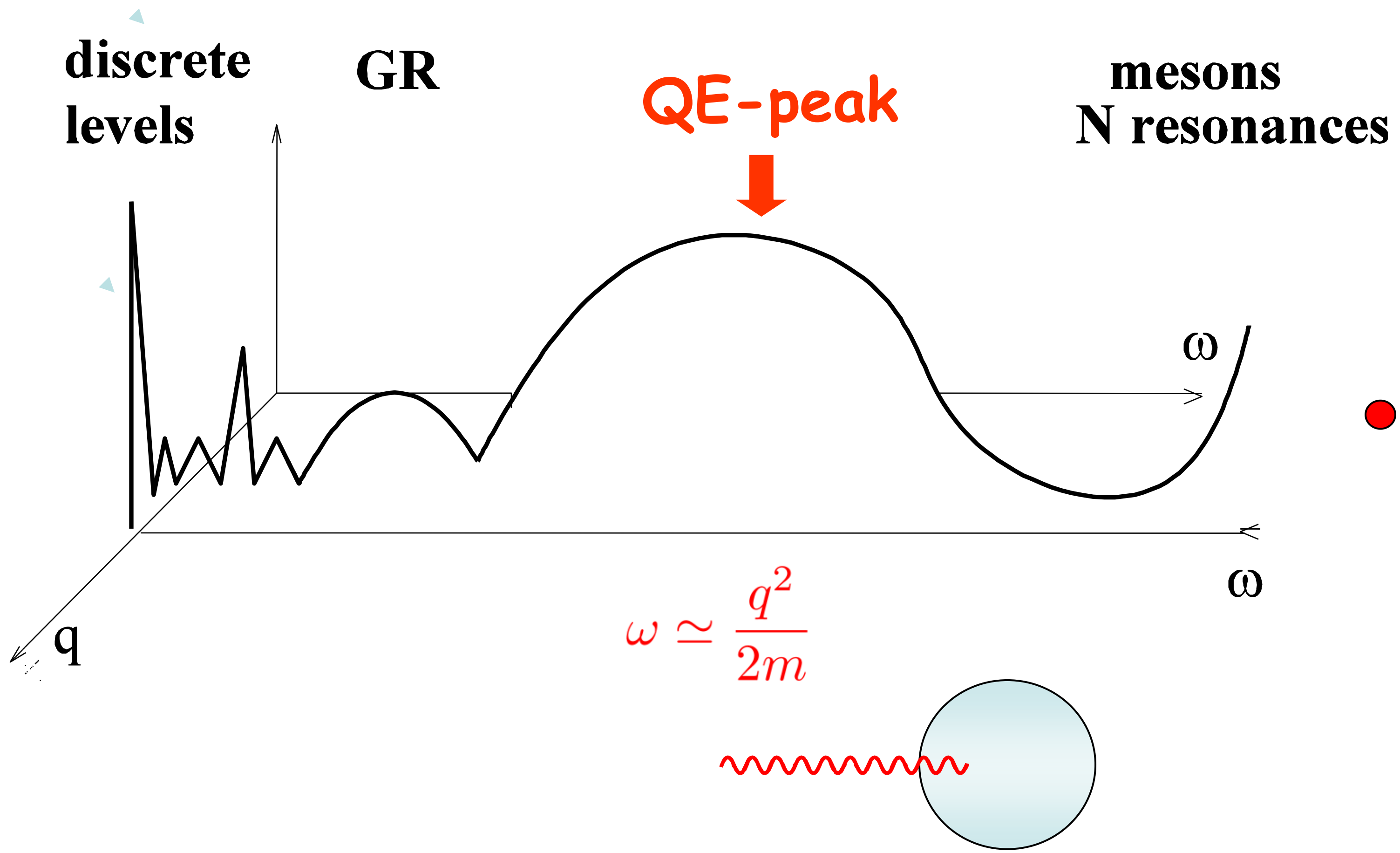


QE-peak dominated by one-nucleon knockout

QE e-nucleus scattering

$$e + A \Longrightarrow e' + N + (A-1)$$

- both e' and N detected (A-1) discrete eigenstate n exclusive (e,e'p)

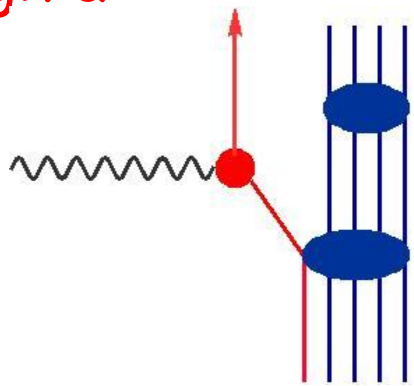
QE e-nucleus scattering

$$e + A \Longrightarrow e' + N + (A-1)$$

- both e′ and N detected (A-1) discrete eigenstate n exclusive (e,e′p)
- only e′ detected, all final nuclear states included inclusive (e,e′)

IMPULSE APPROXIMATION

- EXCLUSIVE SCATTERING: interaction through a 1-body current on a quasi-free nucleon, direct 1NKO



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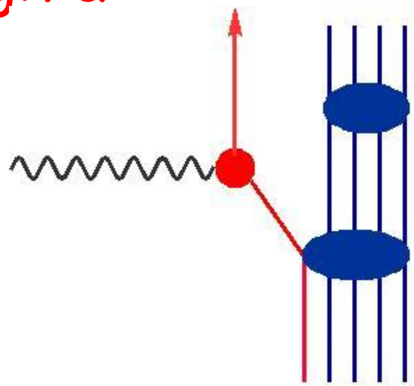
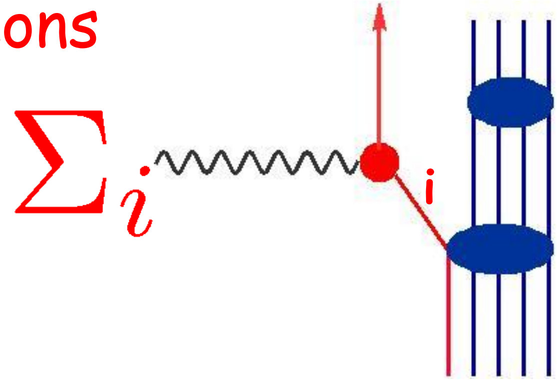


- INCLUSIVE SCATTERING: c.s given by the sum of integrated direct 1NKO over all the nucleons



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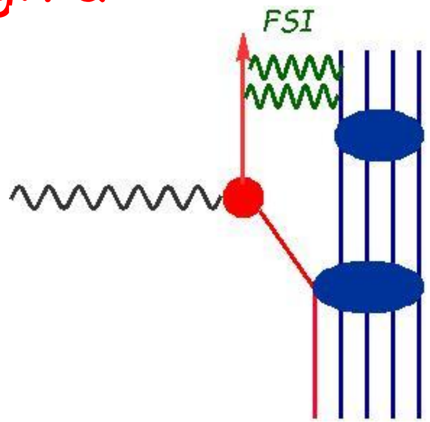

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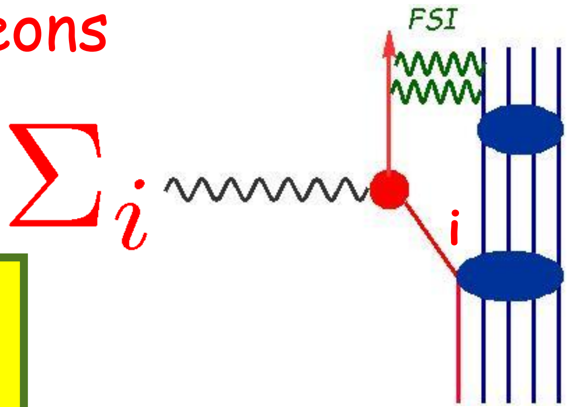


FINAL-STATE INTERACTION between the emitted nucleon and the residual nucleus

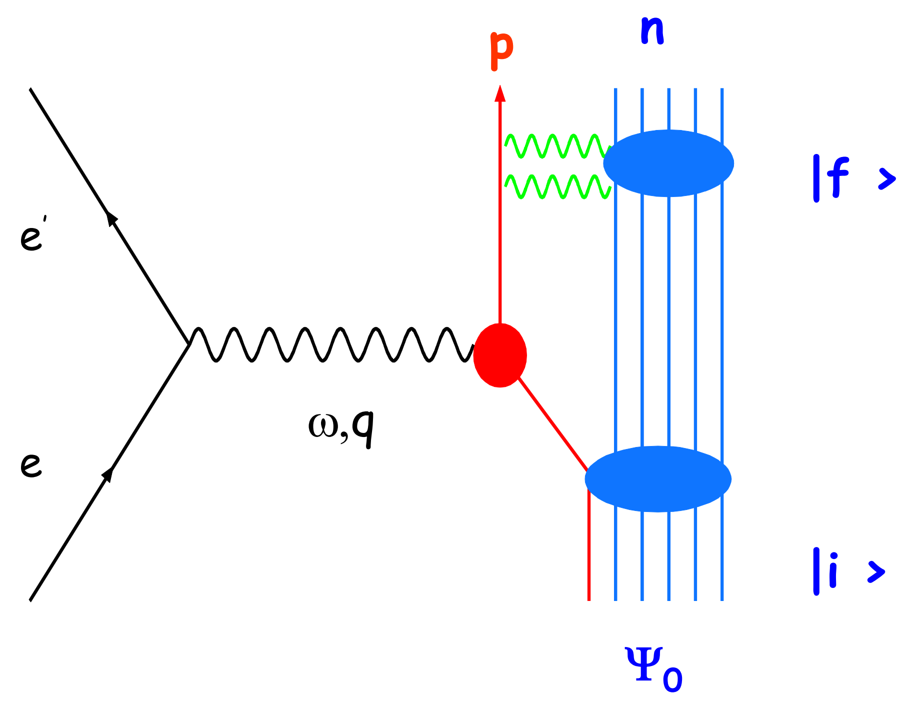
EXCLUSIVE SCATTERING: FSI

RDWIA

FSI described by a complex OP with an imaginary absorptive part. The imaginary part gives a reduction of the calculated c.s. which is essential to reproduce data

DWIA (e,e'p)

- exclusive reaction: n
- DKO mechanism: the probe interacts through a one-body current with one nucleon which is then emitted the remaining nucleons are spectators



$$\langle f \mid J^\mu(\boldsymbol{q}) \mid i\rangle \Rightarrow \lambda_n^{1/2} \langle \chi_{\boldsymbol{p}}^{(-)} \mid j^\mu(\boldsymbol{q}) \mid \phi_n\rangle$$

Direct knockout DWIA (e,e′p)

$$\lambda_n^{1/2} \; \langle \chi^{(-)} \mid j^\mu \mid \phi_n \rangle$$

- j^μ one-body nuclear current
- ϕ_n s.p. bound state overlap function
- λ_n spectroscopic factor
- $\chi^{(-)}$ s.p. scattering w.f. eigenfunction of an OP

INCLUSIVE SCATTERING: FSI

RDWIA

sum of 1NKO where FSI are described by a complex OP
with an imaginary absorptive part does not conserve the flux

INCLUSIVE SCATTERING: FSI

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RPWIA

FSI neglected

INCLUSIVE SCATTERING: FSI

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FSI neglected

REAL POTENTIAL

INCLUSIVE SCATTERING: FSI

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FSI neglected

REAL POTENTIAL

rROP

only the real part of the OP: conserves the flux but it is conceptually wrong

INCLUSIVE SCATTERING: FSI

RDWIA

sum of 1NKO where FSI are described by a complex OP with an imaginary absorptive part does not conserve the flux

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REAL POTENTIAL

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only the real part of the OP: conserves the flux but it is conceptually wrong

RMF

RELATIVISTIC MEAN FIELD: same real energy-independent potential of bound states

INCLUSIVE SCATTERING: FSI

RDWIA

sum of 1NKO where FSI are described by a complex OP with an imaginary absorptive part does not conserve the flux

RPWIA

FSI neglected

REAL POTENTIAL

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RELATIVISTIC MEAN FIELD: same real energy-independent potential of bound states

RGF

GREEN'S FUNCTION complex OP conserves the flux
consistent description of FSI in exclusive and inclusive QE electron scattering

FSI for the inclusive scattering : Green's Function Model

- with suitable approximations (basically related to the IA) the components of the inclusive response can be written in terms of the s.p. optical model Green's function
- the explicit calculation of the s.p. GF can be avoided by its spectral representation which is based on a biorthogonal expansion in terms of the eigenfunctions of the non Herm optical potential V and V^+
- matrix elements similar to RDWIA
- scattering states eigenfunctions of V and V^+ (absorption and gain of flux): the imaginary part redistributes the flux and the total flux is conserved

Relativistic Green's Function Model

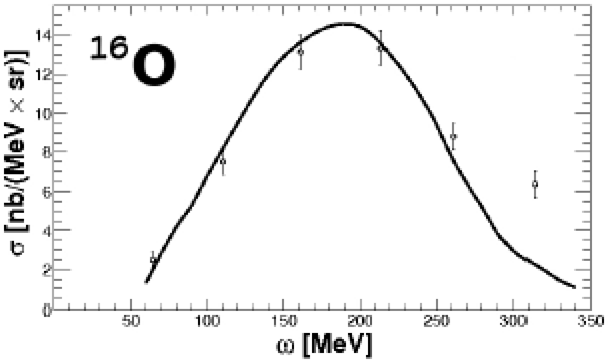
- consistent treatment of FSI in the exclusive and in the inclusive scattering
- the imaginary part of the OP includes inelastic channels
- with a complex OP the model can include contributions not included in other models based on the IA, beyond IA
- energy dependence of the OP reflects the different contribution of the different inelastic channels open at different energies, results sensitive to the kinematic conditions

RGF: successful description of QE data

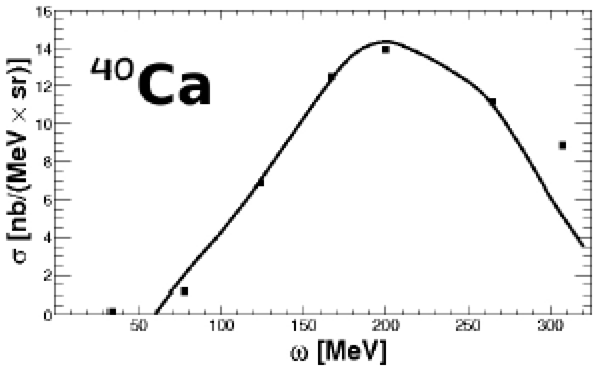
- (e,e′) data
- CCQE and NCE MiniBooNE data
- CCQE MINERvA data

(e,e')

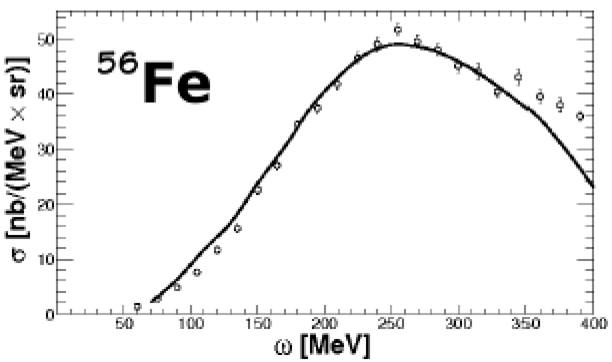
RGF



E_0 = 1080 MeV ϑ = 32°



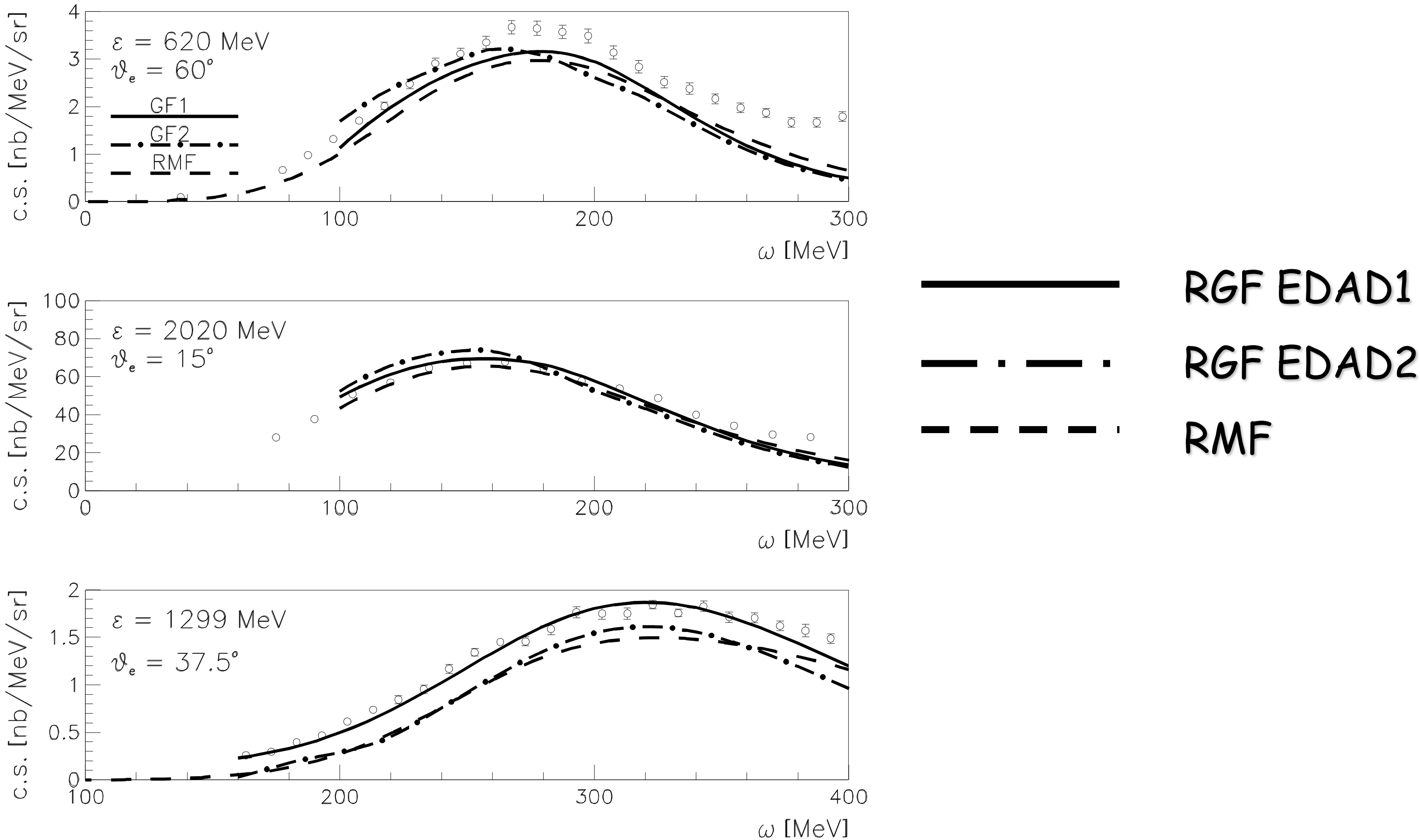
E_0 = 841 MeV ϑ = 45.5°



E_0 = 2020 MeV ϑ = 20°

$^{12}C(e,e')$

relativistic models



A. Meucci, J.A. Caballero, C. Giusti, F.D. Pacati, J.M. Udias PRC 80 (2009) 024605

Differences between Electron and Neutrino Scattering

- electron scattering :

  beam energy known, cross section as a function of ω

- neutrino scattering:

  beam energy and ω not known

  calculations over the energy range relevant for the neutrino flux

the flux-average procedure can include contributions from different kinematic regions where the neutrino flux has significant strength, contributions other than direct 1-nucleon emission

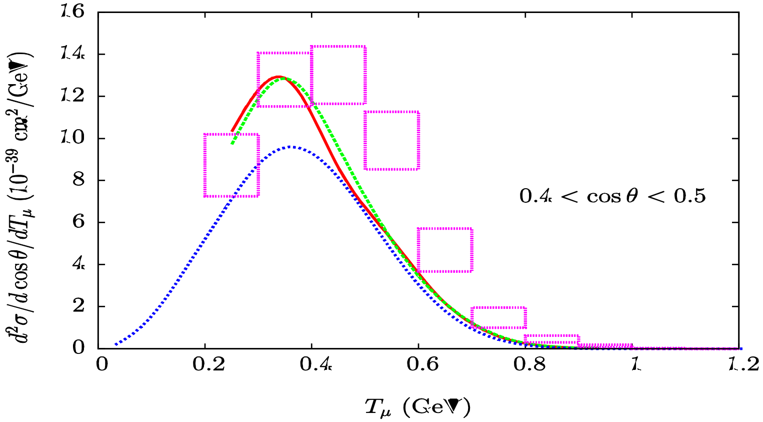
RGF: comparison CCQE data

$$\nu_l(\bar{\nu}_l) + A \longrightarrow l^-(l^+) + N + (A-1)$$

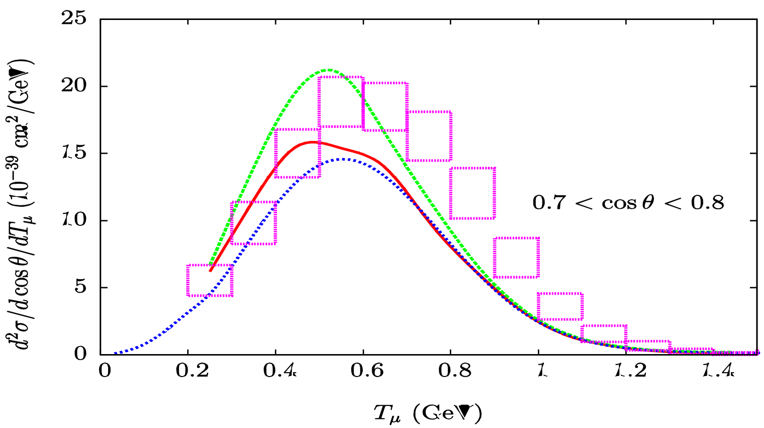
Comparison with MiniBooNe CCQE data

$^{12}C(\nu_\mu, \mu^-)$

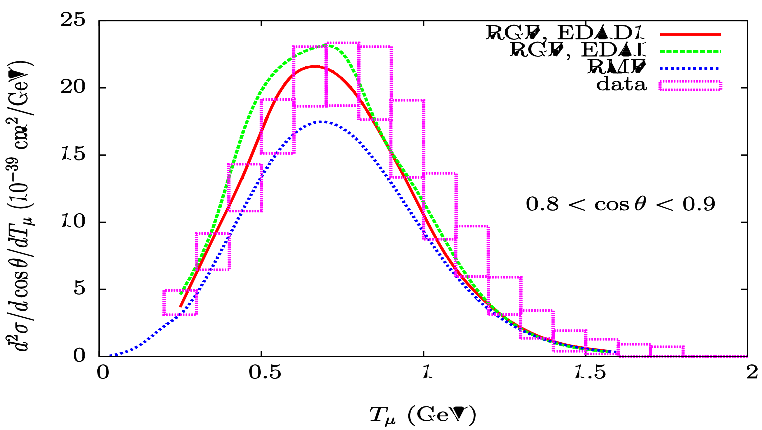
$0.4 < cos\theta_\mu < 0.5$



$0.7 < cos\theta_\mu < 0.8$



$0.8 < cos\theta_\mu < 0.9$



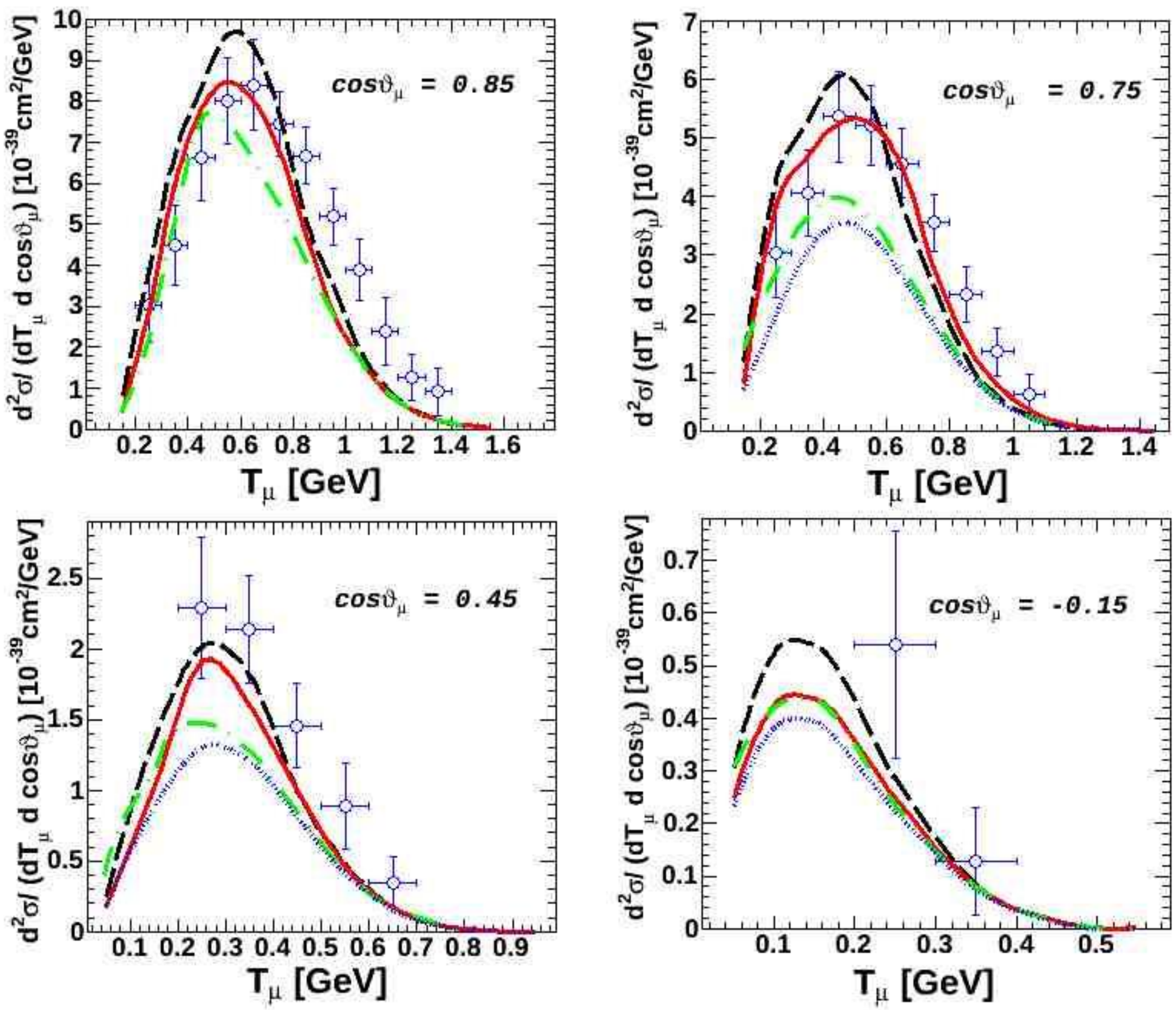
RGF-EDAI

RGF-EDAD1

RMF

A. Meucci et al. PRL 107 (2011) 172501

Comparison with MiniBooNe CCQE data



$$^{12}C(\bar{\nu}_\mu, \mu^+)$$

RPWIA

rROP

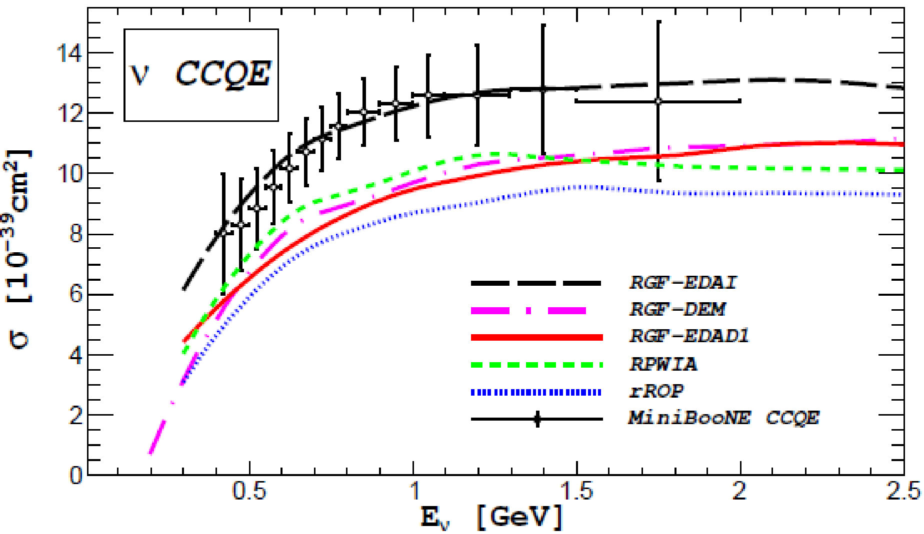
RGF EDAI

RGF-EDAD1

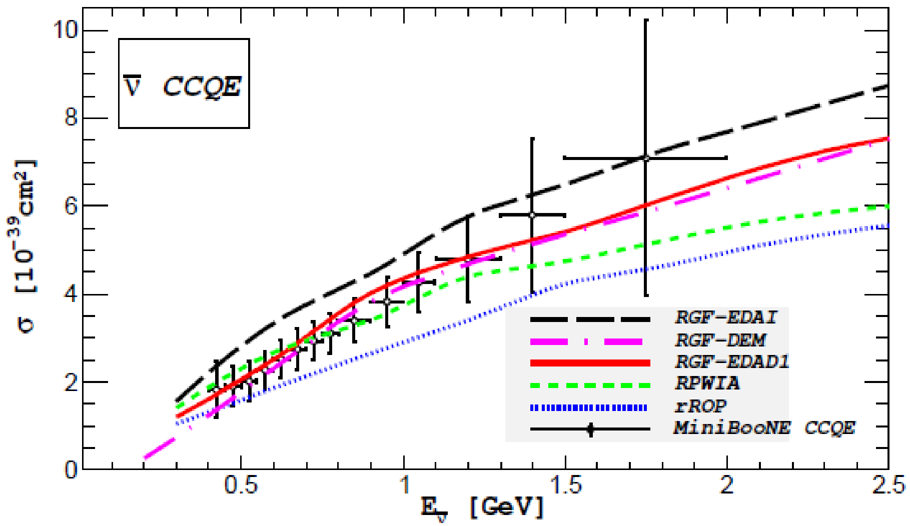
A. Meucci and C. Giusti PRD 85 (2012) 093002

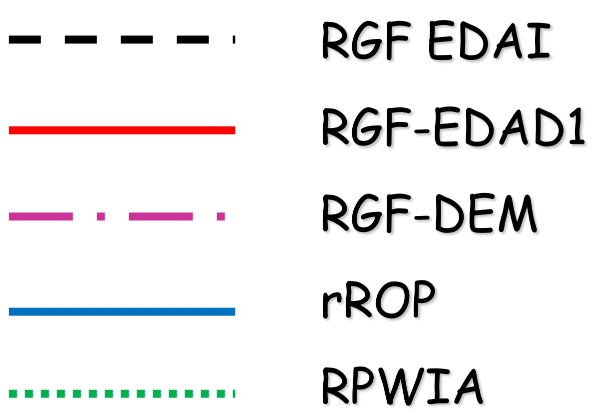
Comparison MiniBooNE CCQE neutrino-antineutrino scattering

$^{12}C(\nu_\mu, \mu^-)$

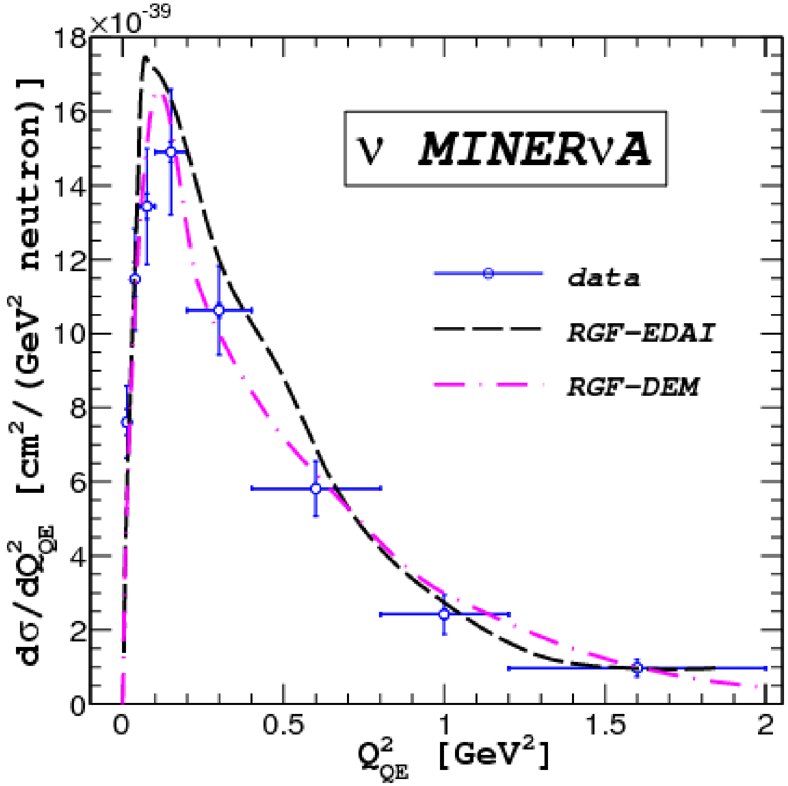


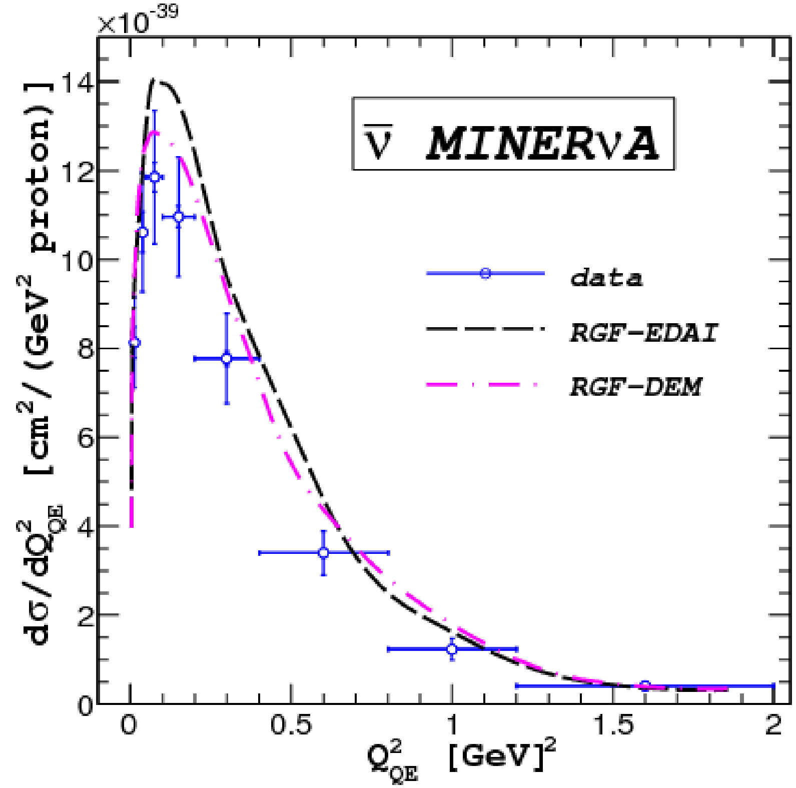
$^{12}C(\bar{\nu}_\mu, \mu^+)$





Comparison MINERνA CCQE neutrino-antineutrino scattering

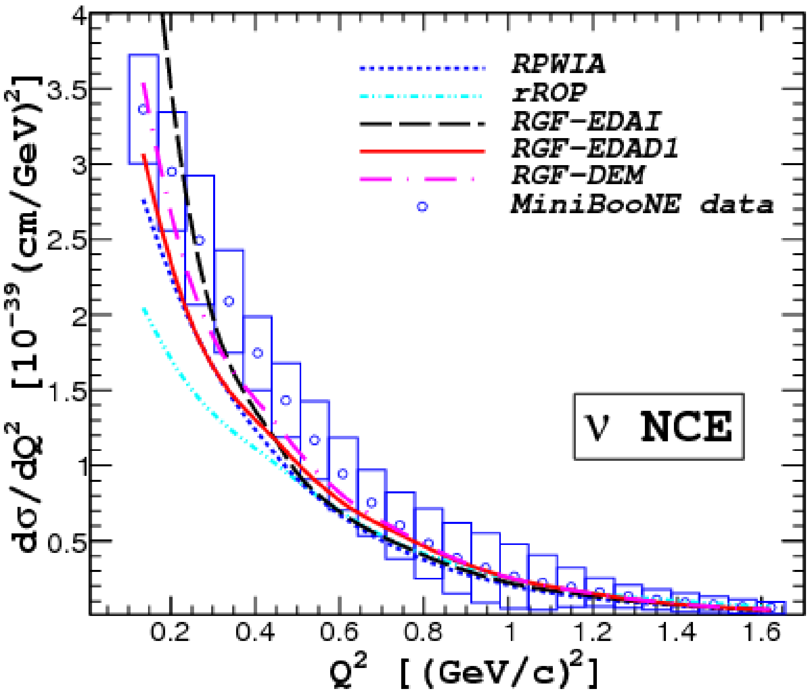


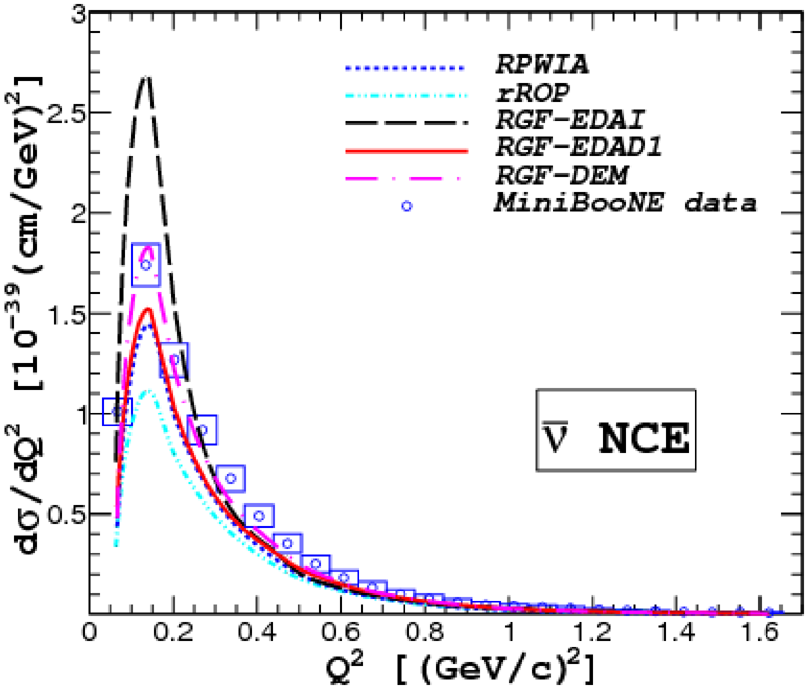


NC ν-nucleus scattering

$$\nu_l(\bar{\nu}_l) + A \longrightarrow \nu_l(\bar{\nu}_l) + N + (A-1)$$

Comparison with MiniBooNE NCE data





A. Meucci and C.Giusti PRD 89 (2014) 057302

RGF

successful in comparison with data: (e,e'), CCQE and NCE MiniBooNE data, MINERvA CCQE data

the imaginary part of the ROP includes the overall effect of inelastic channels (rescattering, non-nucleonic, multi-nucleon….)

a phenomenological ROP does not allow us to disentangle and evaluate the role of specific inelastic processes

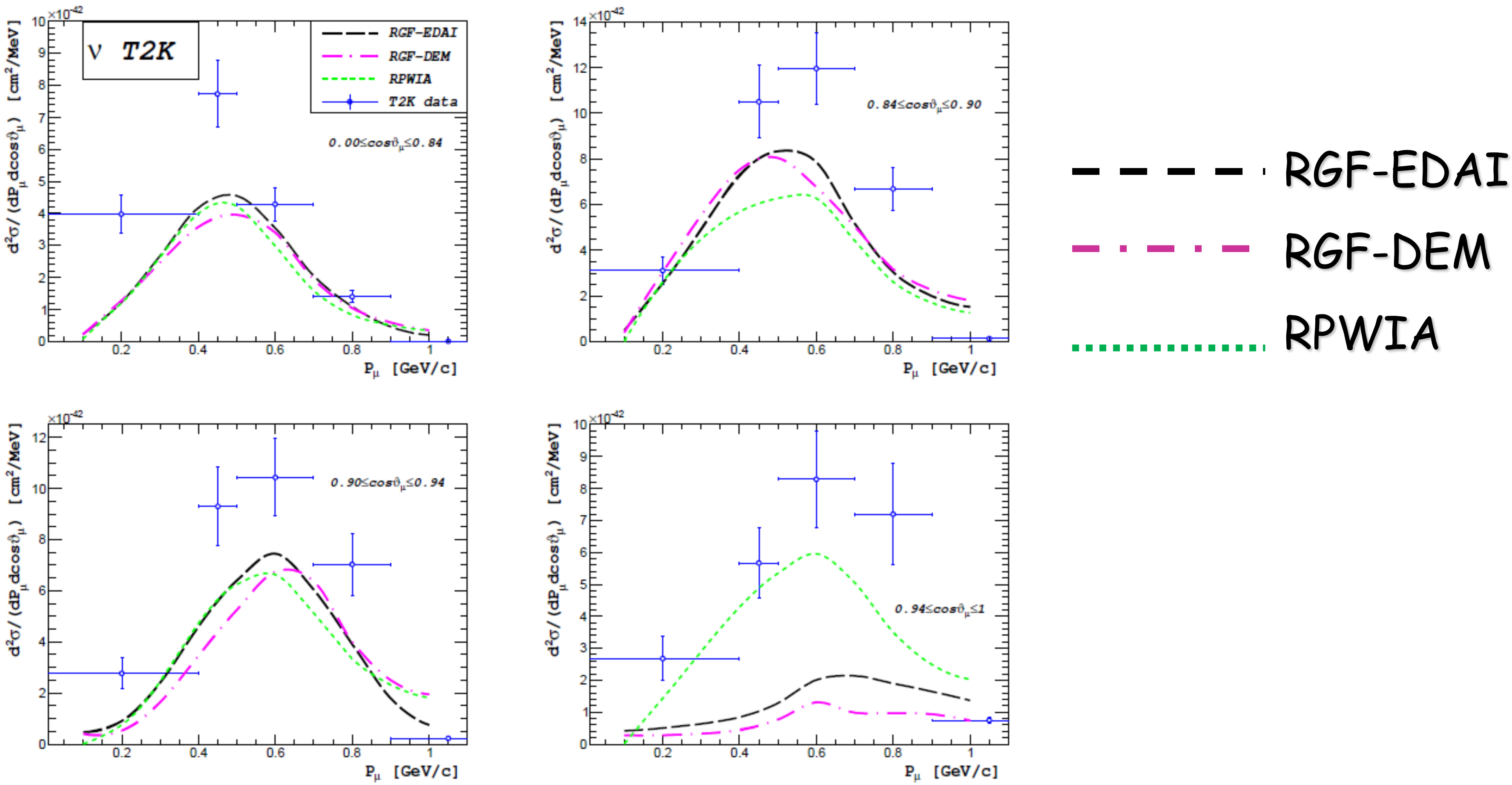
the agreement of the RGF results with data should be interpreted with care

MEC are not included

does the model include also pion production channels?

comparison with T2K CC-inclusive data….

Comparison with T2K CC inclusive data



RGF underestimates CC inclusive data !

RGF

To reduce theoretical uncertainties due to different OPs a less phenomenological optical potential has been obtained for ^{12}C within RIA:

GLOBAL spanning a wide range of nucleon energies (20-1040 MeV)

RELATIVISTIC

FOLDING the relativistic Horowitz-Love-Franey t-matrix for the NN scattering amplitudes with relativistic mean-field nuclear densities via the $t\rho$ approximation

OPTICAL

POTENTIAL

GRFOP

GRFOP

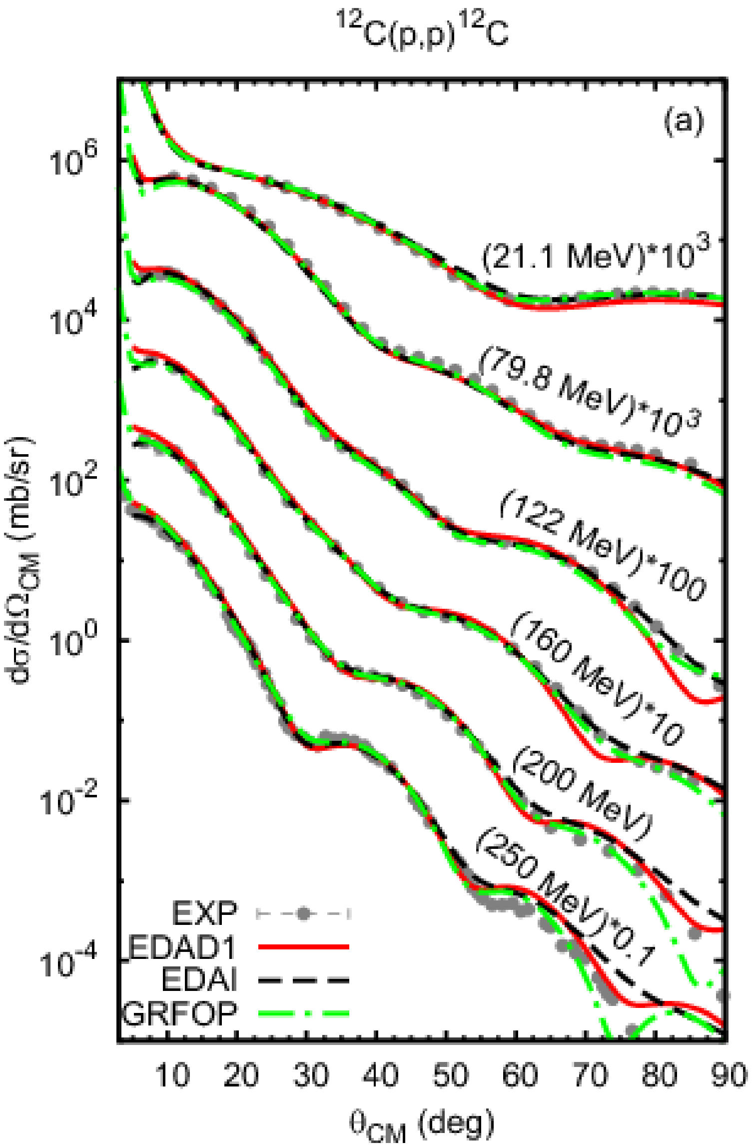
shape dictated by the shape of nuclear densities

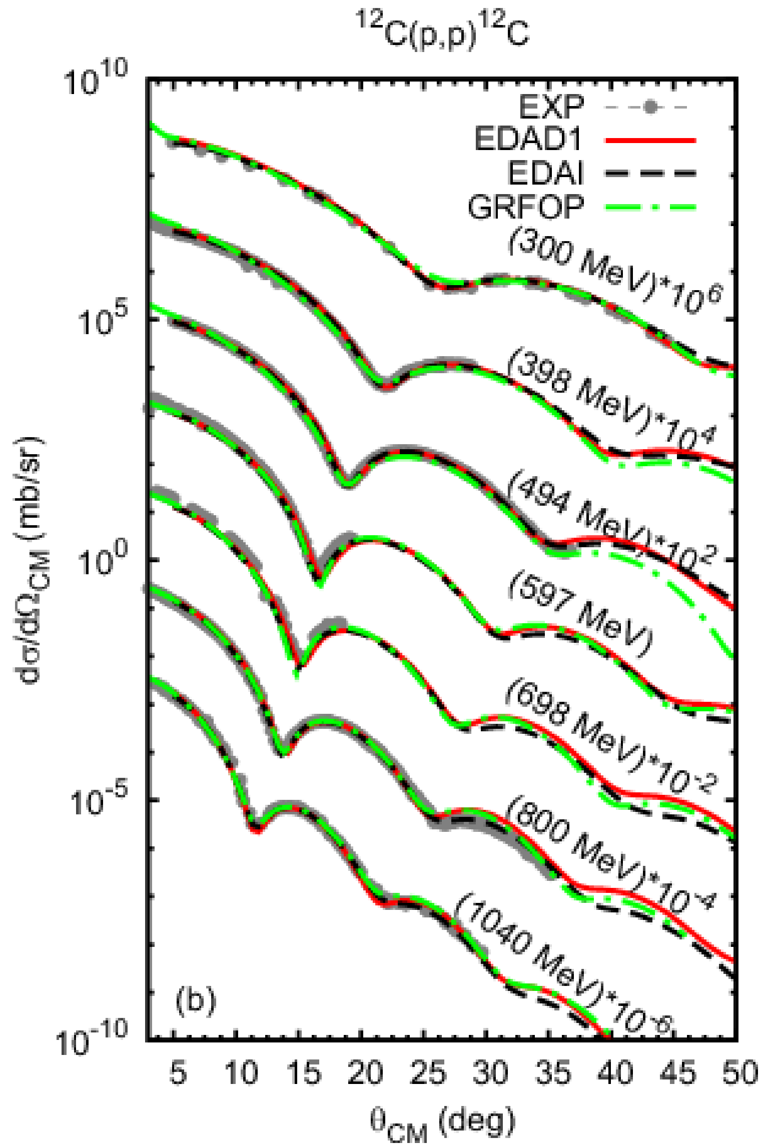
strength dictated by effective parametrizations of the NN scattering amplitudes

GRFOP

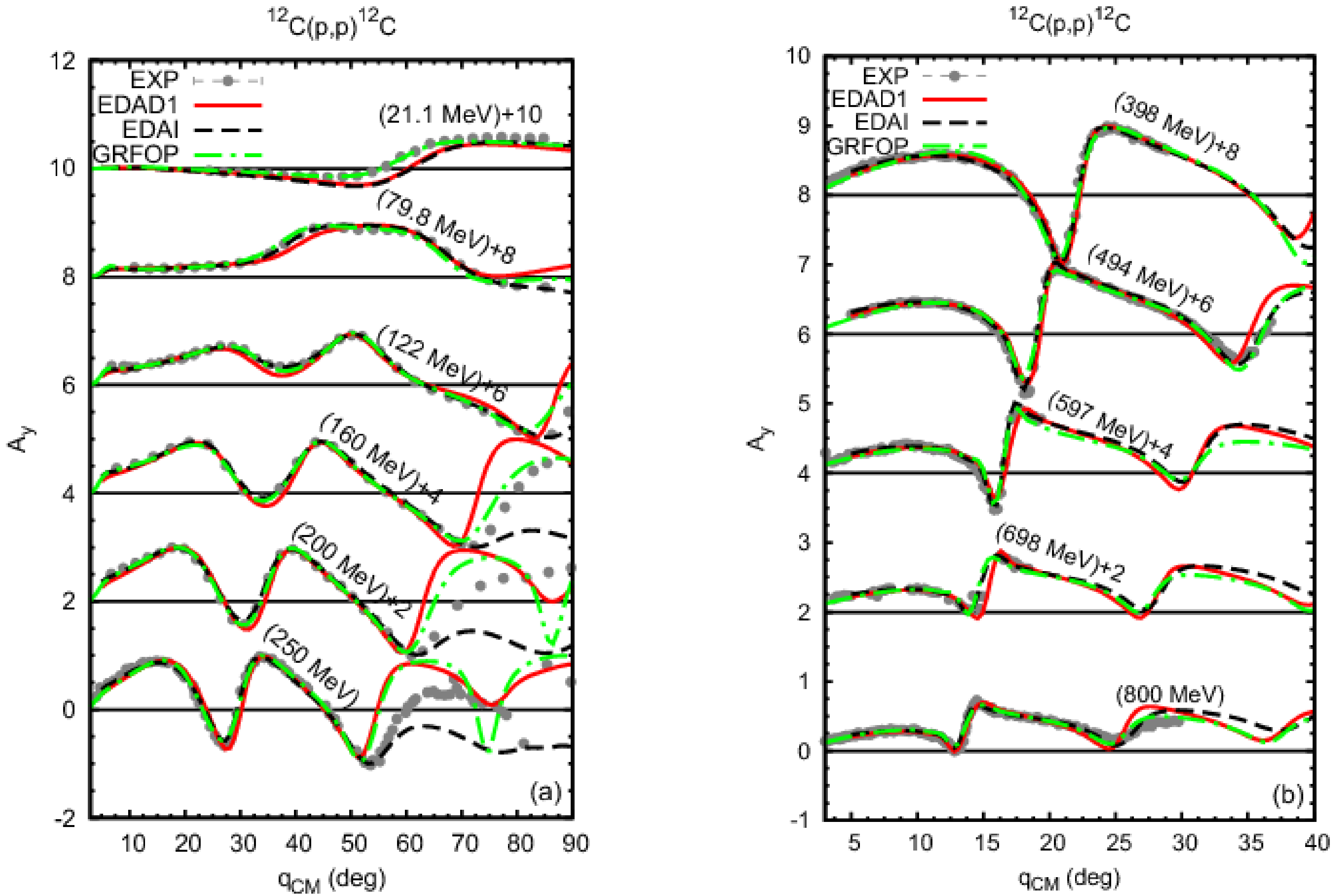
- derived from all available elastic proton-^{12}C scattering data
- folding approach with proton density taken from electron scattering data and neutron density fitted to data
- imaginary part built from the effective NN interaction

$^{12}C(p,p)^{12}C$ cross section

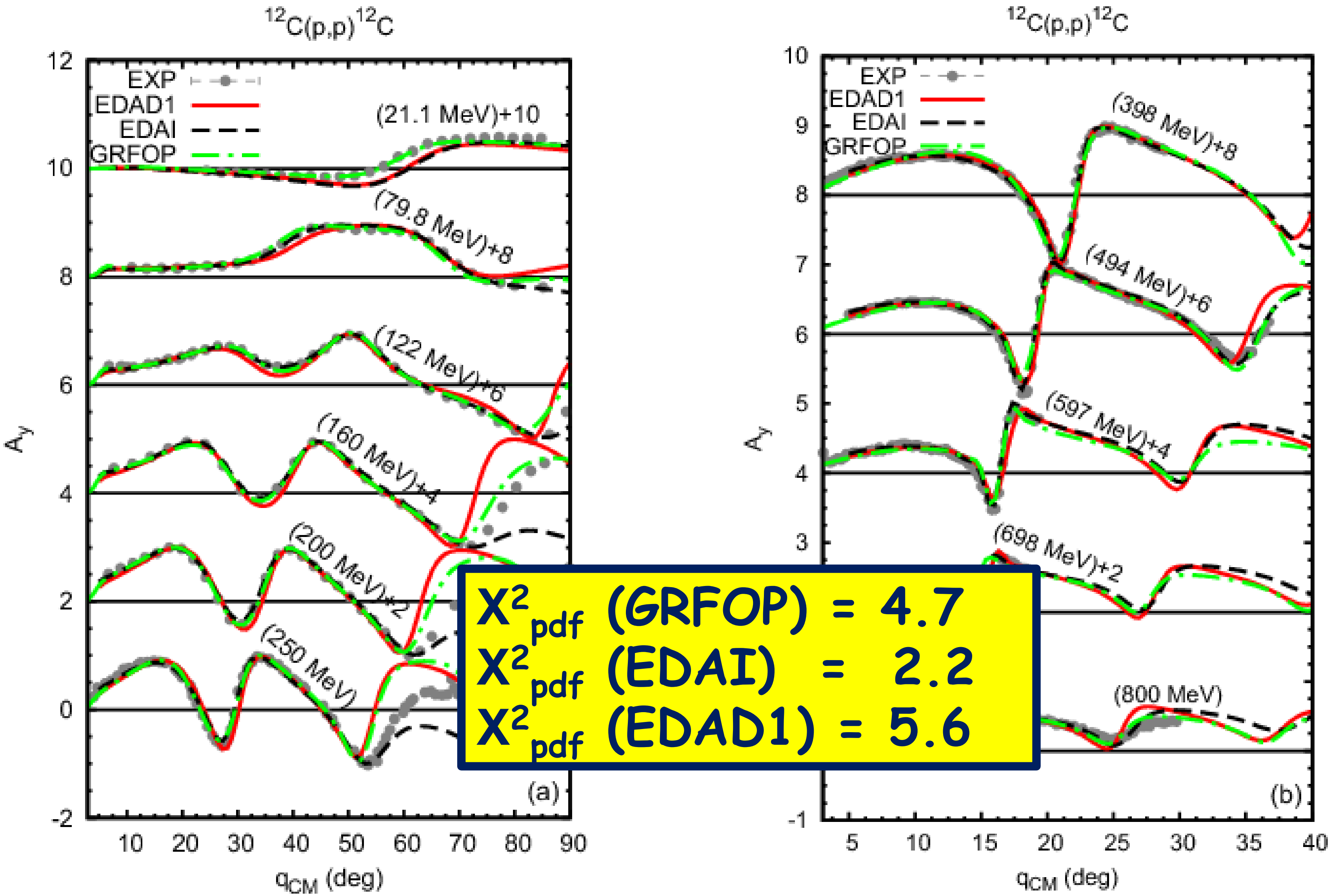




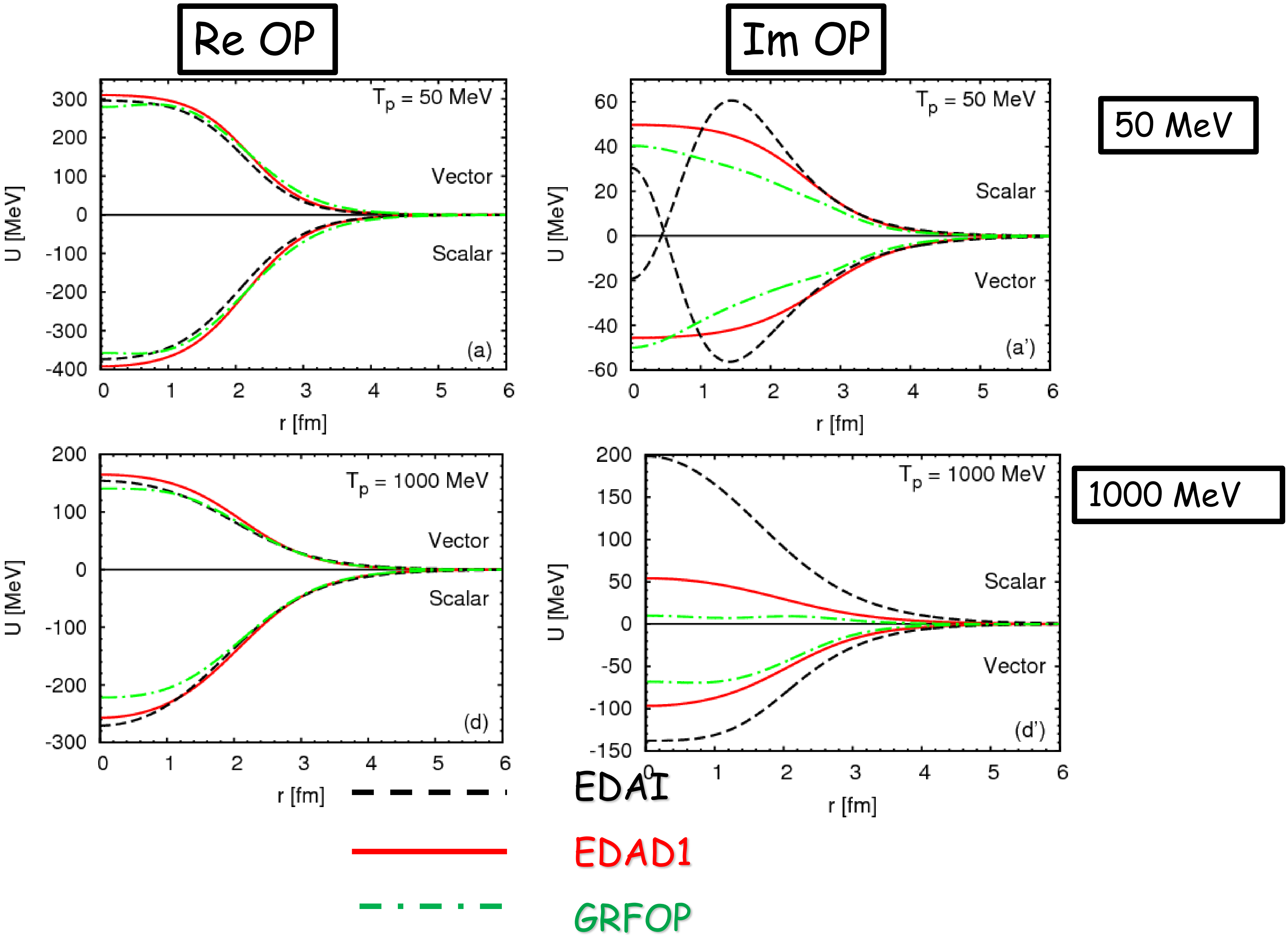
$^{12}C(p,p)^{12}C$ analyzing power



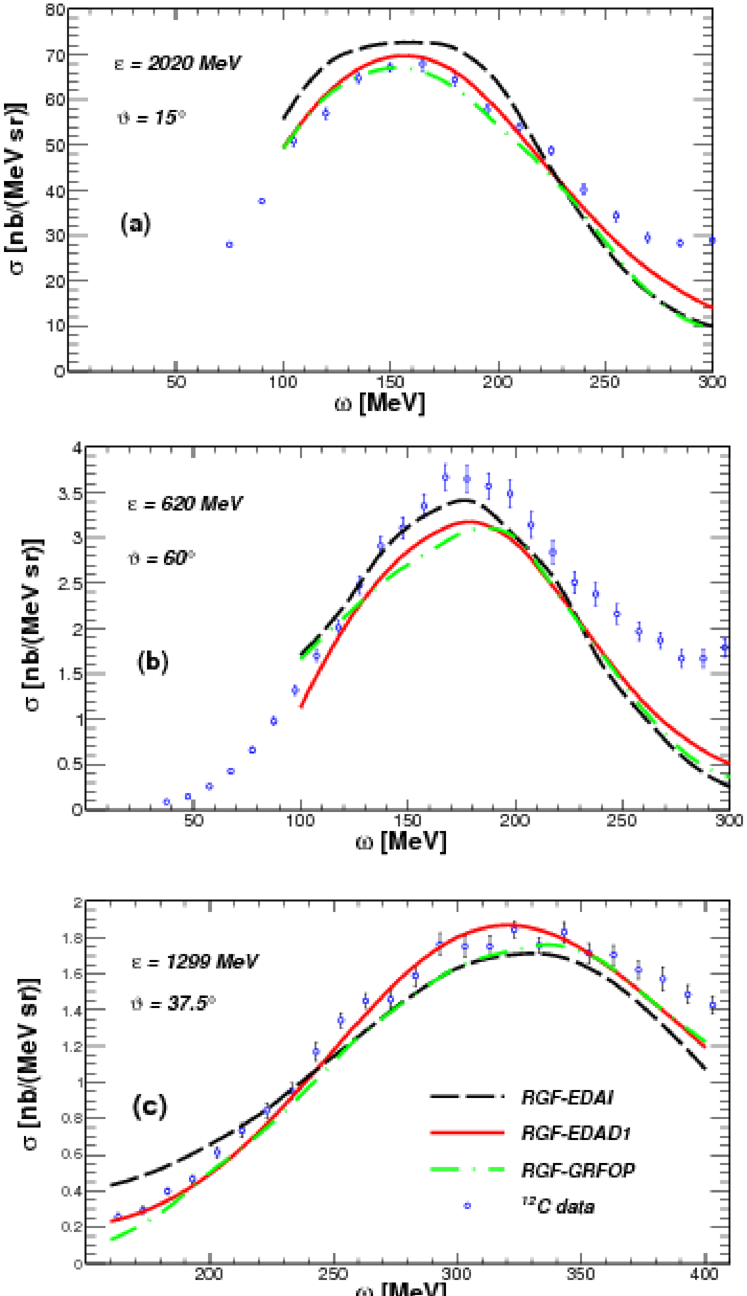
$^{12}C(p,p)^{12}C$ analyzing power



X^2_{pdf} (GRFOP) = 4.7
X^2_{pdf} (EDAI) = 2.2
X^2_{pdf} (EDAD1) = 5.6


Re OP
Im OP
50 MeV
1000 MeV
T_p = 50 MeV
Vector
Scalar
(a)
U [MeV]
r [fm]
T_p = 50 MeV
Scalar
Vector
(a')
U [MeV]
r [fm]
T_p = 1000 MeV
Vector
Scalar
(d)
U [MeV]
r [fm]
T_p = 1000 MeV
Scalar
Vector
(d')
U [MeV]
r [fm]
EDAI
EDAD1
GRFOP

$^{12}C(e,e')$



ϵ =2020 MeV

θ = 15°

ϵ =620 MeV

θ = 60°

RGF-EDAI

RGF-EDAD1

RGF-GRFOP

ϵ =1299 MeV

θ = 37.5°

SCALING FUNCTION

The analysis of (e,e') data has demonstrated the validity of scaling arguments

At sufficiently high q the scaling function $f = \dfrac{d^2\sigma(q,\omega)/d\Omega dk'}{S^{s.n.}(q,\omega)}$

depends only upon one kinematical variable (scaling variable)

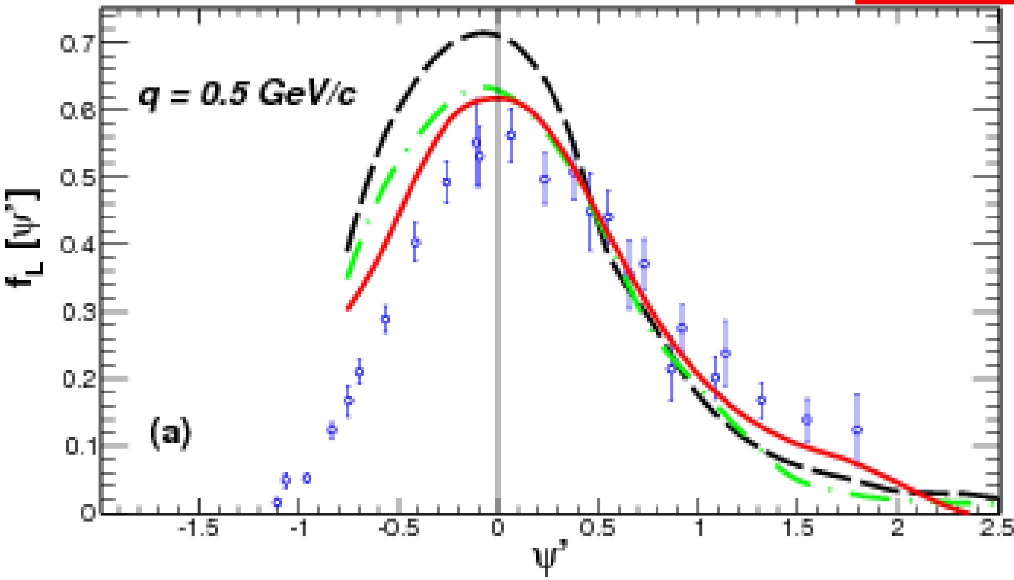
(SCALING OF I KIND)

is the same for all nuclei

(SCALING OF II KIND)

I+II SUPERSCALING

QE SCALING FUNCTION

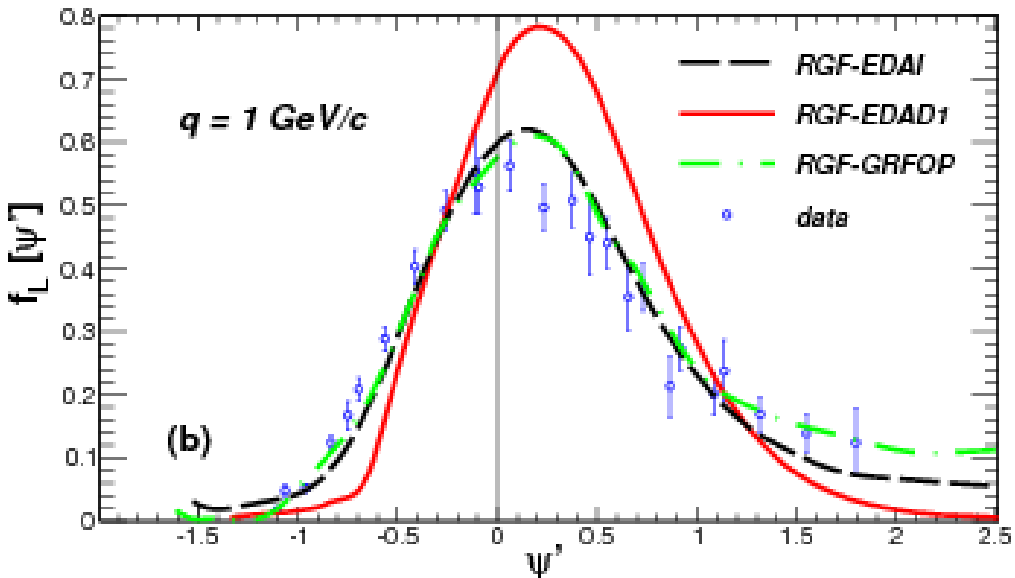


q=500 MeV/c

RGF-EDAI

RGF-EDAD1

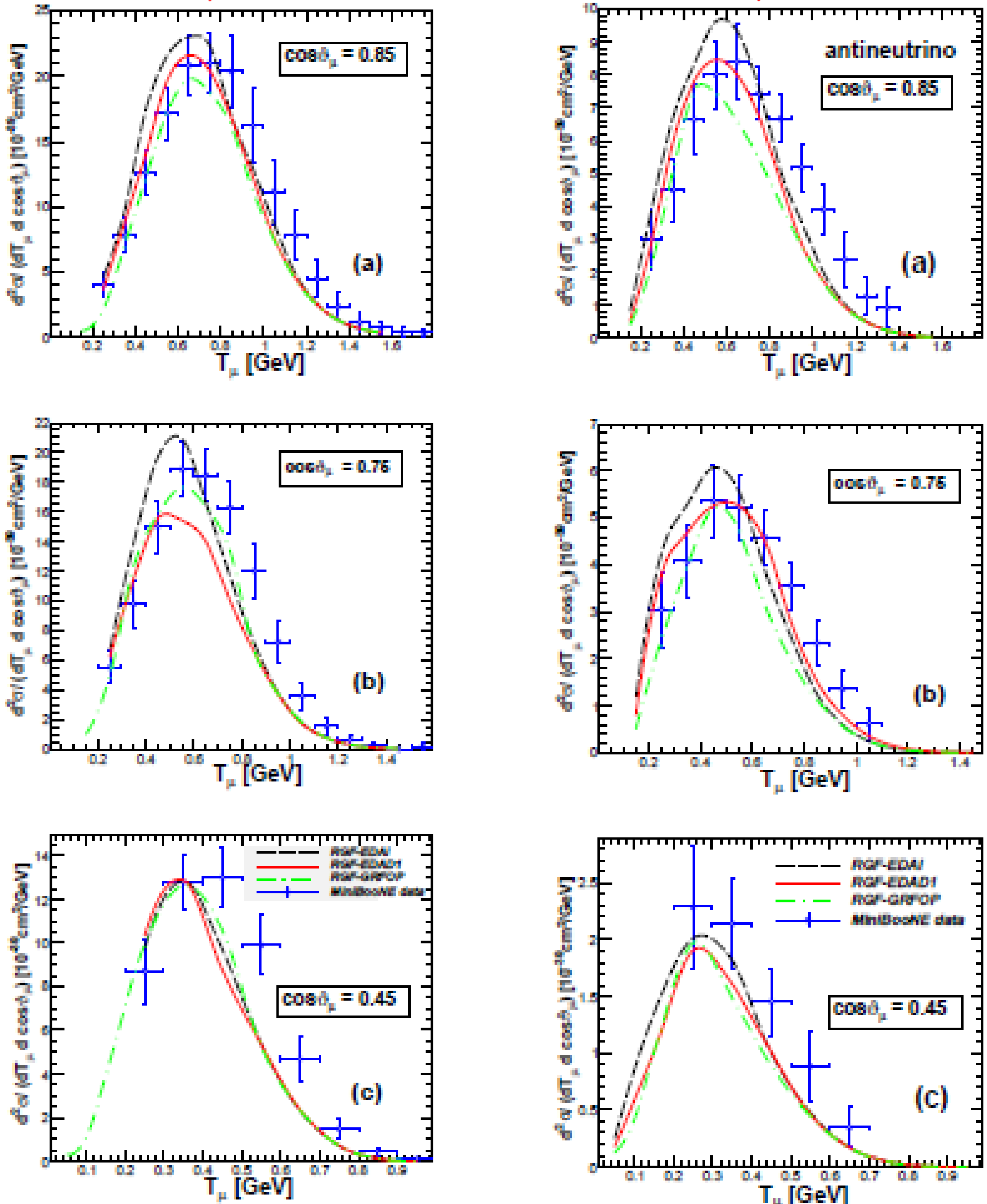
RGF-GRFOP

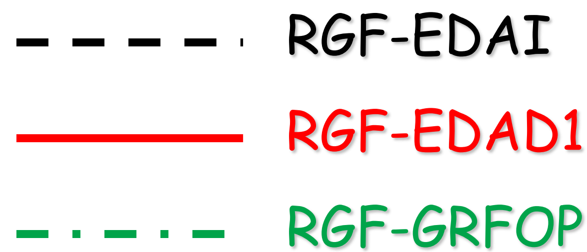


q=1 GeV/c

MiniBooNe CCQE data

$^{12}C(\nu_\mu, \mu^-)$ $\qquad$ $^{12}C(\bar{\nu}_\mu, \mu^+)$

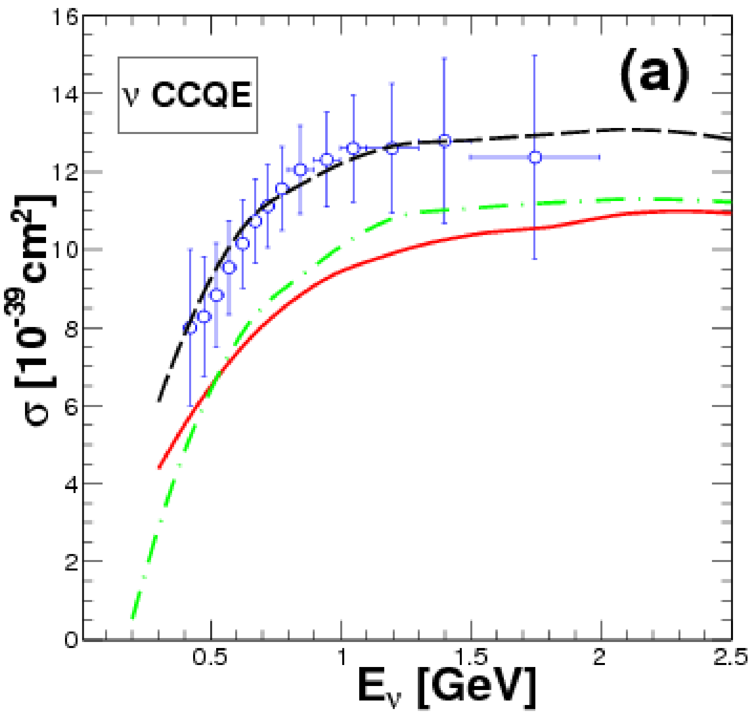


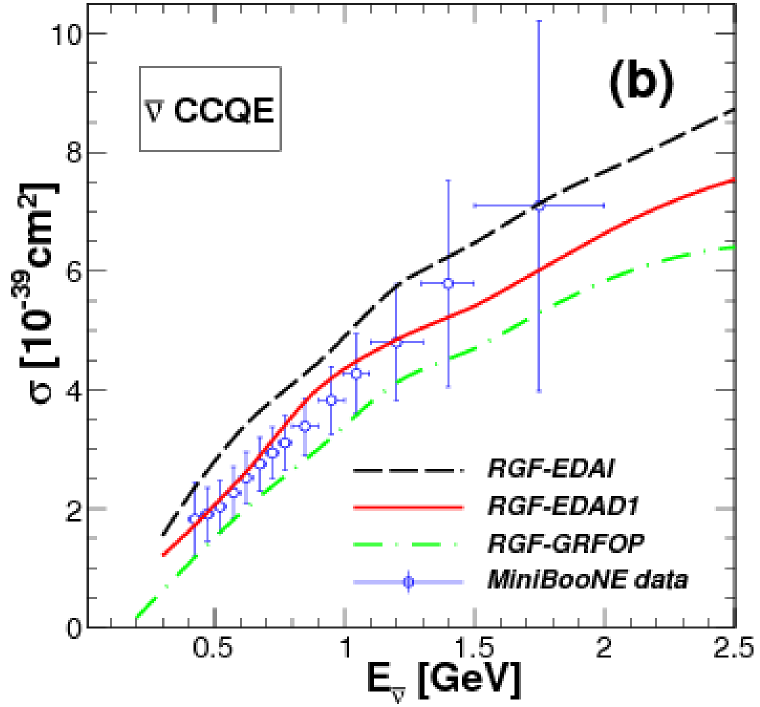


MiniBooNe CCQE data

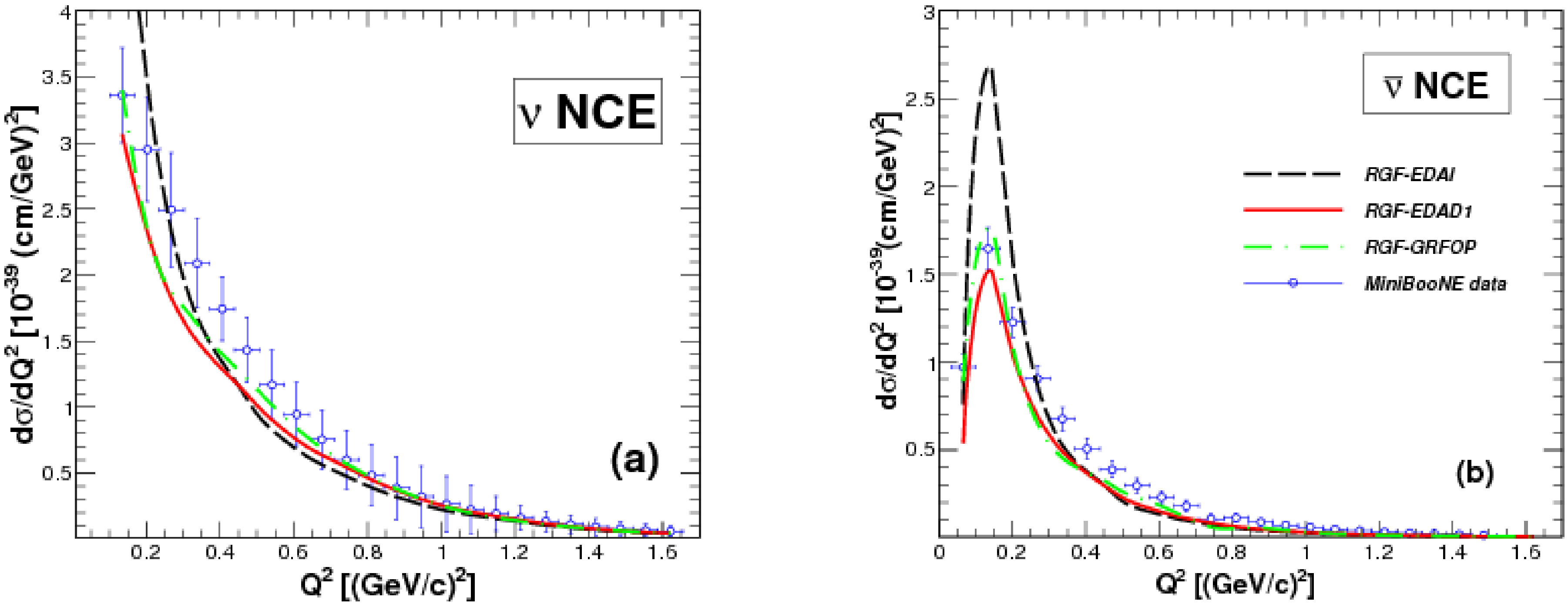
$^{12}C(\nu_\mu, \mu^-)$

$^{12}C(\bar{\nu}_\mu, \mu^+)$





MiniBooNE NCE data



RGF-GRFOP

- generally between RGF-EDAI and RGF-EDAD1 results
- in many cases in better agreement with data
- good agreement with (e,e′) data
- good agreement with the experimental scaling function
- reasonable agreement with CCQE and NCE data
- use of GRFOP reduces the theoretical uncertainties in RGF predictions and confirms previous findings in comparison with data
- RIA can provide successful Dirac optical potentials able to fit elastic nucleon-nucleus scattering data and useful alternatives to phenomenological OP
- GRFOP can be improved extending the range of validity of the parametrization or including an A-dependence
- OP can be employed for calculations on a wide variety of nuclear reactions where the OP is a crucial and critical input